important feature in the work for which the association exists.

Those in attendance at the meeting may obtain information of all sorts by applying at the information desk in the registration room. Before the meeting, information may be obtained from the secretaries of the sections or of the associated societies (regarding programs, etc.), from the chairman of the local committee, Professor J. Paul Goode, of the University of Chicago regarding local arrangements, or from the permanent secretary's office in Washington regarding general association affairs.

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A MORE NEARLY RATIONAL SYSTEM OF UNITS

SYSTEMS of units for physical magnitudes are designed to permit arithmetical calculations on the basis of known physical laws, and the test of the efficiency of any system is the extent to which it facilitates such computations. There are two ways, in particular, in which this can be accomplished: first, by relating the units of any one magnitude in a manner consistent with the system of arithmetic in use; with a decimal arithmetic this requires that the ratio of such units be a power of 10, *e. g.*, the erg and the joule; second, by so relating the units of different "dimensions" as to prevent the appearance of arbitrary and irrational factors in the equations expressing the fundamental laws of natural science, *e. g.*, the "gas law" should take the form "pressure = concentration × temperature" ($P = CT$) rather than "pressure is proportional to concentration × temperature" ($P = CRT$). The failure of the "English" system of weights and measures to meet these requirements is a matter of common knowledge, but it seems worth while to point out how little superior in these respects is the present "metric" system.

The common basis of both these systems of physical and chemical units comprises: (1) the decimal arithmetic, (2) the mean solar second and (3) the table of atomic weights based on O ≡ 16. It is not intended here to discuss these fundamentals, beyond pointing out that no one of them is entirely rational, and if they are retained it will be only because the difficulties in the way of superseding them outweigh the advantages of a change. The purpose of this paper is an inquiry whether on this common foundation there can be construed a system of units superior to either of the two now in common use.

1. Two systems of arithmetic with a base other than 10 are suggested by the methods of division of units in the case of "English" weights and measures (*a*) the twelve-system, illustrated by the dozen and gross and by the divisions of the foot and the pound Troy; (*b*) the two-system, illustrated by the divisions of the inch, the gallon and the pound avoirdupois. Both modes of division are used in coinage, though not at all consistently, (*a*) in the case of the shilling of twelve pence, (*b*) in the penny of four farthings and the distinctly non-decimal division of the dollar into quarters (and even into "bits" of 12½ cents). In a recent eulogy of the twelve-system (SCIENCE, N. S., 50, 239–242 (1919)), Dr. William Benjamin Smith says:

"This best of numerical systems is not the ten-system (which is recommended only by the fact that man has ten fingers and ten toes!) but the twelve-system, whose virtues are imbedded in the nature of number itself."

2. The humor of basing a decimal system of weights and measures on a unit of time obtained by dividing the mean solar day successively into 24, 60 and 60 parts, hardly needs emphasis. The mean solar day is the average interval between the passage of the sun across the meridian for any locality. The maximum difference between mean solar time and true solar time is 16 minutes (about November 1 of each year).

3. The change from the H ≡ 1 system of atomic weights to the present O ≡ 16 was made both because of the uncertainty of the H: O ratio and because the oxygen standard made more of the atomic weights approximate whole numbers. Re-

[1] Forty-first Contribution from the Color Laboratory of the Bureau of Chemistry, Washington, D. C.

sults lately obtained on the atomic weights of the *isotopes* of lead and of neon indicate that one sixteenth of the atomic weight of oxygen is very near indeed to the unit mass of the Prout hypothesis, but it is highly improbable that it should be identical with it. (It would require that oxygen consist of one isotype only—or a still less probable balancing of heavy and light isotopes.)

The most flagrant case of irrationally related metric units is that of electrical quantity, for which four units, no two of which are commensurable, are in actual use. These four are (1) the electrochemical equivalent of electricity, or Faraday, (2) the coulomb, which is one tenth of the centimeter-gram-second electromagnetic unit, (3) the centimeter-gram-second electrostatic unit and (4) the "Heaviside" electrostatic unit, differing from the foregoing by the factor $1/\sqrt{4\pi}$, and used by Lorentz and others in electron theory calculations in order to give a simple form to the fundamental equations for the electromagnetic field. The ratio of the electromagnetic to the electrostatic unit is numerically the same as the velocity of light, hence a reconciliation is possible only in a system which makes the numerical velocity of light a power of 10. A unit of the Heaviside type is quite satisfactory for practical use, hence the adoption of such a unit would obviate the necessity of having one unit for theoretical and another for practical work. Finally, by a suitable selection of a unit of mass the electromagnetic and electrochemical units can be brought into harmony. (It should be noted that this involves giving up the use of water as a standard of density.) To summarize: it is possible—by making the numerical value of the velocity of light a power of 10, by suitably choosing the unit of mass, and by using the Heaviside definition of unit charge—to derive a single unit of electrical quantity suitable for all purposes.

Heat and temperature units are to be derived by purely dynamic definitions, without regard to the properties of the substance, water. Unit temperature is the temperature at which unit concentration of a "perfect gas" exerts unit pressure on the walls of its container; while the difference between the heat capacities of a mol of "perfect gas" at constant pressure and at constant volume is the unit of heat capacity and of entropy.

In Table I. are given the numerical factors which, in various combinations, are involved in conversion between the proposed units and those of the centimeter-gram-second system.

TABLE I

Symbol	Definition	Numerical Value[2]
4π	Ratio of area of sphere to square of radius	12,5664
10^9	Numerical value assigned in proposed system to the velocity of light and to the electrochemical equivalent[3]....	12.5664
c	Velocity of light in c.g.s. units	29,986,000,000. cm. per sec.
E	Electrochemical equivalent[3] in c.g.s. units	9,647.2 units per equivalent
R	Gas constant in c.g.s. units	83,150,000. ergs per mol per °C.
J	Value of the mean calorie in c.g.s. units	41,850,000. ergs per calorie

Tables II., III. and IV. give the ratios of the proposed units to those of the metric system—both algebraically in terms of the factors terms listed in Table I., and numerically. Numerical values are given only when the metric unit compared has a name in common use.

The names for multiples and submultiples of the fundamental units would be formed with the prefixes now in use in the metric system, *e. g.*, the kilo-unit of electric current and the mega-units of pressure and of temperature would probably be used more than the fundamental units; but, aside from the preference of one multiple or submultiple to another, the

[2] The values for the last four are taken from Kaye and Laby's tables.

[3] The quantity of electricity required to deposit electrolytically one equivalent of metal. E, the electricity in c.g.s. electromagnetic units per equivalent, is used instead of F, the number of coulombs per equivalent, to avoid mixing engineering and c.g.s. units.

TABLE II

Geometric, Kinematic and Mechanical

Unit of		In Terms of C.G.S. Unit		In Terms of Engineering Unit
Distance	$\frac{c}{10^9}$	29.986 cm.	$\frac{c}{10^{11}}$	0.29986 m.
Area	$\frac{c^2}{10^{18}}$	898.92 sq. cm.	$\frac{c^2}{10^{22}}$	0.089892 sq. m.
Volume	$\frac{c^3}{10^{27}}$	26951. c.c.	$\frac{c^3}{10^{33}}$	0.026951 cu. m.
Time	1	1 sec.	1	1 sec.
Velocity	$\frac{c}{10^9}$	29.986 cm. per sec.	$\frac{c}{10^{11}}$	0.29986 m. per sec.
Acceleration	$\frac{c}{10^9}$	29.986 cm. per sec.^{2}	$\frac{c}{10^{11}}$	0.29986 m. per sec.^{2}
Mass	$\frac{c}{4\pi E^2}$	25.636 g.	$\frac{c}{4\pi 10^3 E^2}$	0.025636 kg.
Concentration	$\frac{10^{30}}{4\pi c^2 E^2}$	0.9512 molal		
	$\frac{10^{27}}{4\pi c^2 E^2}$	0.0009512 g. per c.c.		
Momentum	$\frac{c^2}{4\pi 10^9 E^2}$	768.62 g. cm. per sec.	$\frac{c^2}{4\pi 10^{14} E^2}$	0.0076862 kg. m. per sec.
Force	$\frac{c^2}{4\pi 10^9 E^2}$	768.62 dyne	$\frac{c^2}{4\pi 10^{14} E^2}$	0.0076862 j. per m.
Pressure	$\frac{10^9}{4\pi E^2}$	0.85504 dyne per cm.^{2} (bar)	$\frac{10^8}{4\pi E^2}$	0.085504 j. per m.^{3}
Energy	$\frac{c^3}{4\pi 10^{18} E^2}$	23045. erg.	$\frac{c^3}{4\pi 10^{25} E^2}$	0.0023045 joule

units in engineering and scientific work would be identical.

The advantages to be gained are indicated by the following statement of some of the points of difference from both the English and the metric system. In the proposed system:

The fundamental unit of capacity (liquid measure) is the cube of the unit of length.

Astronomic units of distance now in use, "light second," "light hour," etc., are commensurable with the units proposed, the first being one *billion* times the fundamental unit of length.

Under "standard conditions" one mol of "perfect gas" occupies unit volume.

The difference between the specific heats of a "perfect gas" at constant pressure and at constant volume is 1.

Unit current in electrolysis deposits per second one *billionth* of an equivalent of metal.

The electrostatic capacity of an air condenser and the permeance of a magnetic air gap (or a magnetic circuit in air) are each one *billionth* of their respective "shape factors."[4]

The electric flux from a charge is equal to the charge, and the magnetic flux from a magnetic pole is equal to the pole strength.

The magnetomotive force, per turn, of a coil is equal to the current flowing through it.

The electromotive force, per turn, generated in a coil is equal to the rate of change of the flux within it.

The energy of an electric, or magnetic, field is equal to one half the product of the flux and, respectively, the electromotive or magnetomotive force.

[4] "Flow of Heat through Furnace Walls; the Shape Factor," Irving Langmuir, E. Q. Adams and G. S. Meikle, *Trans. Amer. Electrochem. Soc.*, 24, 53 (1914).

TABLE III

Electric and Magnetic

Unit of	In Terms of C.G.S. Unit		In Terms of Engineering Unit	
	Electrostatic	Electromagnetic		
Charge	$\frac{c^2}{4\pi 10^9 E}$	$\frac{c}{4\pi 10^9 E}$	$\frac{c}{4\pi 10^8 E}$	0.0024732 coulomb
Current	$\frac{c^2}{4\pi 10^9 E}$	$\frac{c}{4\pi 10^9 E}$	$\frac{c}{4\pi 10^8 E}$	0.0024732 ampere
Potential	$\frac{c}{10^9 E}$	$\frac{c^2}{10^9 E}$	$\frac{c^2}{10^{17} E}$	0.9318 volt
Capacity	$\frac{c}{4\pi}$	$\frac{1}{4\pi c}$	$\frac{10^9}{4\pi c}$	0.0026542 farad
Resistance	$\frac{4\pi}{c}$	$4\pi c$	$\frac{4\pi c}{10^9}$	376.74 ohms
Energy	$\frac{c^3}{4\pi 10^{18} E^2}$	$\frac{c^3}{4\pi 10^{18} E^2}$	$\frac{c^3}{4\pi 10^{25} E^2}$	0.0023045 joule
Flux	$\frac{c}{10^9 E}$	$\frac{c^2}{10^9 E} =$		93180000 gauss
Density	$\frac{10^9}{cE}$	$\frac{10^9}{E} =$		103660 maxwell
Magnetomotive force	$\frac{c^2}{10^9 E}$	$\frac{c}{10^9 E} =$		0.0031079 gilbert
Reluctance	c	$\frac{1}{c} =$		0.000000000033353 oersted
Energy	$\frac{c^3}{4\pi 10^{18} E^2}$	$\frac{c^3}{4\pi 10^{18} E^2} =$		23045 erg

TABLE IV

Thermal

Unit of	In Terms of Calorimetric Units		In Terms of C.G.S. Units	
Heat capacity	$\frac{cR}{4\pi E^2 J}$	50.934 calories per g. per ° C.	$\frac{cR}{4\pi E^2}$	2131600000. ergs per g. per ° C.
Entropy	$\frac{cR}{4\pi E^2 J}$	50.934 calories per g. per ° C.	$\frac{cR}{4\pi E^2}$	2131600000. ergs per g. per ° C.
Temperature	$\frac{c^2}{10^{18} R}$	0.000010811 degree	$\frac{c^2}{10^{18} R}$	0.000010811 degree
Energy	$\frac{c^3}{4\pi 10^{18} E^2 J}$	0.00055064 calorie	$\frac{c^3}{4\pi 10^{18} E^2}$	23045. erg

A few examples of the working of the system of units follow. It has been thought best not to attempt to coin names for the proposed units, hence the values will be given without designation unless a multiple or submultiple of the fundamental unit has been used, when the abbreviation of the appropriate Metric prefix will be added (μ, micro-; m, milli-; c, centi-; d, deci-; D, deka; H, hecto-; K, kilo-; M, mega-).

Find the capacity of a vat of length 10, width 5 and depth 4. Answer: $10 \times 5 \times 4 = 200$

Find the volume of a sphere of 1 light second radius. Answer:

$$\tfrac{4}{3}\pi(10^9)^3 = \tfrac{4}{3}\pi \times 10^{27}.$$

Find the molecular weight of a substance, a mass of 15 m of which occupies a volume of 12 m, at a temperature of 30 M and a pressure of 1.2 M. Answer:

$$\frac{15 \times 30}{12 \times 1.2} = 31.25.$$

Find the time required with an electric current of 10 K and a potential of 100 to heat unit mass of helium (atomic weight, 4) through a temperature interval of 10 M, at constant pressure. (The specific heat of a monatomic gas at constant *volume* is 3/2.) Answer:

$$\frac{\frac{1}{4} \times 10^7 \times (\frac{3}{2} + 1)}{10^4 \times 100} = 62.5 \text{ sec.}$$

Find the mass of copper (valence 2, at.wt. 63.57) that would be deposited by a current of 10 K in 1,000 sec. Answer:

$$\frac{63.57 \times 10^4 \times 1{,}000}{2 \times 10^9} = 0.318.$$

Find the capacity of a condenser with 100 sheets of dielectric (of dielectric constant 2) each of unit area and thickness 0.01. Answer:

$$\frac{100 \times 1 \times 2}{10^9 \times 0.01} \begin{array}{l} = 2 \times 10^{-5} \\ = 20\mu. \end{array}$$

Find the inductance of a coil of 100 turns wound on a closed core of iron of permeability 1,000, of cross section 0.2 × 0.2 and length of magnetic circuit 4. Answer:

$$\frac{\overline{100}^2 \times 1{,}000 \times .2 \times .2}{10^9 \times 4} = 10^{-4}.$$

Find the magnetic energy of the core when a current of 1 K is passing through the coil. Answer:

$$\tfrac{1}{2} \times (10^3)^2 \times 10^{-4} = 50.$$

In conclusion, it should be noted that the foregoing is primarily a description of a method of deriving a system of units, and that a system of substantially equal convenience could be devised with an other than decimal arithmetic, a different unit of time or another basis of atomic weights.

SUMMARY

1. On the common foundation of the English and metric systems of units there can be constructed a system superior to either.

2. Its bases are (1) the mean solar second, (2) a length of 29.986 cm. and (3) a mass of 25.636 g.

3. Tables of the relation of the various units in this system to the corresponding metric units are given.

4. A single set of units serves for both engineering and scientific purposes.

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PALEONTOLOGY AND PRAGMATISM

Two recent publications of the United States National Museum admirably illustrate a phase of the scientific activities of the government to which I have long thought of calling attention, since they are accomplished without noise or press notices and are of immense value to the people as a whole in addition to their intrinsic scientific worth.

The publications to which I refer are North American Early Tertiary Bryozoa, by Canu and Bassler, constituting Bulletin 106, and Contributions to the Geology and Paleontology of the Canal Zone, by T. Wayland Vaughan and associates, constituting Bulletin 103. More particularly I wish to refer to the work of Canu and Bassler on the Bryozoa, Joseph A. Cushman on the Foraminifera, Marshall A. Howe on the calcareous algæ, and T. Wayland Vaughan on the corals.

These are all groups of organisms whose habits are exceedingly interesting and whose forms are often highly artistic, but none of which furnish food for commercial fishes or humanity, or are objects of trade,[1] or yield any gums, wax, gems, or minerals that might make them seemingly worth while to the man in the street.

The Bryozoa are inconspicuous colonial animals, some of them with a beauty all their own, but seldom appreciated since they require magnification in order to be seen to advantage. Some are usually included in amateur collections of so-called sea weeds, but to the average person a bryozoan is as unknown as a native of Mars. The recently installed sea

[1] The red coral of commerce and its imitations are exceptions, but these are European and not American products and do not affect the force of the statement.